Land Report

Number 126, Spring 2020 · The Land Institute

About The Land Institute

MISSION STATEMENT
When people, land and community are as one, all three members prosper; when they relate not as members but as competing interests, all three are exploited. By consulting nature as the source and measure of that membership, The Land Institute seeks to develop an agriculture that will save soil from being lost or poisoned, while promoting a community life at once prosperous and enduring.

OUR WORK
Thousands of new perennial grain plants live year-round at The Land Institute, prototypes we developed in pursuit of a new agriculture that mimics natural ecosystems. Grown in polycultures, perennial crops require less fertilizer, herbicide and pesticide. Their root systems are massive. They manage water better, exchange nutrients more efficiently and hold soil against the erosion of water and wind. This strengthens the plants' resilience to weather extremes, and restores the soil's capacity to hold carbon. Our aim is to make conservation a consequence, not a casualty, of agricultural production.

LAND REPORT
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TO REACH US
The Land Institute
2440 E. Water Well Road,
Salina, KS 67401
phone 785-823-5376
fax 785-823-8728
info@landinstitute.org

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Cover

Interns Siena Polk and Crystal Ma harvest perennial wheat last July. Ma, from the Seattle area, was studying biology and studio art at Williams College in Massachusetts. Polk, from Sun Valley, Idaho, was majoring in international studies and food studies at the University of Oregon. The Land Institute depends on a dozen or more interns each year to help grow, harvest, and process its perennial grain crops. Scott Seirer photo.

Sarah Crews found her calling in returning naturalness – and hands-on directness – to funerals and burials. With ground donated by The Land Institute, she founded Heart Land Prairie Cemetery. In the foreground is a simple disc, with name and dates, to mark one of Heart Land's graves. Scott Bontz photo.

Rest in perennials

No embalming or steel coffins, but hands-on deliverance to nature

SCOTT BONTZ

At 7:30 a.m. one day last August, Melanie Mann, her sister, brother-in-law, and an uncle arrived at Heart Land Prairie Cemetery, five acres of woods bordering eight acres of grassland that bear not one memorial stone. With shovels and a combination of axe and hoe called a Pulaski, the family set about breaking and lifting heavy clay soil to clear a space about six feet long and four feet deep. It was hard work; they finished about 11:15 a.m. Next morning, they folded down a minivan's seats and drove to Elliott Mortuary & Crematory in Hutchinson, Kansas. Melanie's mother, Linda, lay there in a white shroud that smelled of sage. The family drove with her for an hour and quarter to the cemetery in Ottawa County, northeast of The Land Institute. A tarp had been removed from over the grave they'd dug. On the bottom of the grave lay an inch of prairie grass. Her kin laid Linda across three straps, and with those lowered her into the ground. Atop her they put more dried grasses, and with shovels they covered her with soil. They sprinkled the mound with a mix of prairie seeds, and on it placed roses.

Linda Mann had played piano and organ for church and orchestra, for weddings and funerals, and as a high school recital accompanist. "She brought music everywhere she went, and always went above and beyond what would be normally expected", Melanie said. She called her mother's life sense one of "active service". Burying her by use of their bodies, not machines, and without machine noise, Melanie said, "Felt like an act of service for my mom".

Linda also had a high environmental consciousness, was someone for whom even cremation, with its fuel cost and emissions including mercury, would have seemed a violation. She was not embalmed. Melanie said her family is practical, and "There's nothing practical about embalming". The mortuary agreed to simply keep Linda's body cool. She had no coffin, just the linen shroud purchased directly from its maker.

Linda hadn't known about Heart Land, but Melanie and her uncle learned of it online. The sisters visited the cemetery, and they felt their mother would've appreciated its rural peace and birdsong. "We just felt really good about the place". And burying Linda themselves felt intimately profound in a way that a hired funeral could not be. "I'm also thinking that I would rather be buried this way", Melanie said.

Heart Land is the work of Sarah Crews. She promotes the cemetery as part of nature, and also teaches how to hold funerals at home and more naturally conclude someone's life with their care at death. But a home funeral is not required for burial at Heart Land.

Sarah is married to Land Institute ecologist and researcher Tim Crews. They lived

in Prescott, Arizona, when, after staying at home with their two young daughters, Sarah returned to teaching art and playing music in a nursing home. She was often called to bring her guitar and sing at the bedside of someone who was dying. These experiences moved her. She began work with hospice as a music caregiver and bereavement counselor, then earned a bachelor's degree in Aging and End-of-Life, and a master's in Spiritual Care at End-of-Life. At a retreat about dying, another attendee told her something like, "If you really want to provide spiritual care at the end-of-life, you ought to look into how you can help *after* someone dies".

Sarah didn't immediately see the link. But in hospice work she watched many a coffin lowered by machine, with family and friends of the dead left as bystanders on Astroturf. Only after the loved ones had driven away came burial, by strangers. The coffin was steel, often ornate, but never to be seen again. Sarah also heard from a woman shocked by the unrecognizable smile on her mother's face as arranged by the embalmer. And she was finally struck in the heart by Mark Harris's book "Grave Matters". There she learned how people could avoid artificiality's spiritual and financial toll by burying the beloved themselves, without formaldehyde, steel, or concrete. "This is something I felt very deep in my bones", Sarah said.

She is not the only one. The Green Burial Council lists more than 200 participating cemeteries. They are changing not only how we handle our dead, but making the cemetery landscape more about life and its cycles. Heart Land's burial ground is being restored to prairie. Other cemeteries restore forests. This serves wildlife, and people can enjoy nature while paying respects to their loved ones – who, unlike with conventional burial's aims, are part of nature. There's no embalming and no vaults, both common practices though not a single state requires either. Burial containers are biodegradable: cotton sheet, felted wool, silk, linen, muslin, wood, cardboard, bamboo, wicker. Graves are shallower and better for decomposition than the typical five to six feet dug for vaults, but deep enough to not attract scavengers.

With the exception of the likes of pharaohs, such treatment of the dead had been the rule for human beings until the American Civil War. Bodies stayed at home, sometimes even in bed, for a day or two before returning to earth untreated, their decomposition to make life anew delayed by no more than a box of wood. Jews and Muslims still strive for burial on the day of death, and embalming is forbidden. But as Brian Walsh reports in Smithsonian Magazine, during the war Americans who could afford it embraced French chemist

Jean-Nicolas Gannal's "arterial embalming", often with arsenic and mercury, to bring home dead sons rather than leave them on the battlefield or in a mass grave. Abraham Lincoln encouraged the new technology, with Elmer Elsworth, the first Union officer killed in the war, lying in state at the White House. Lincoln's 11-year-old son, Willie, was embalmed. The same doctor embalmed Lincoln three years later. The body made a three-week tour by train from Washington to burial in Springfield, Illinois, and exhibit of the presidential corpse made a national sensation. Now, with embalming as its "cornerstone", Walsh writes, dealing with death in America is professionalized, and the National Funeral Directors Association figures the average arrangement at $9,000.

"What isn't as easy to quantify is what we've traded off as communities and families by keeping death at arm's length", Sarah said. Her goal is to connect land and loved ones. She encourages, almost *requires*, survivors to lower the body into the grave. "Get everyone involved in participating in every aspect of the burial. We've unintentionally relegated ourselves as spectators during one of life's most profound transitions. We know how to bury our own dead. We did it for millennia. This is an ordinary task that's become culturally unfamiliar. But ask ordinary people to engage in this ordinary task and they have an extraordinary experience".

After Tim Crews took the job of research director at The Land Institute and the couple moved to Kansas, Sarah proposed a natural cemetery. The Board of Directors for the institute, whose mission is about connecting community and land, donated the Niles acreage. A nonprofit corporation was formed for Heart Land. It raised $10,000 for a maintenance trust, and $5,000 for equipment, including to dig graves – only Linda Mann's family has done it by hand. 8.5 acres were dedicated to burial ground, and this was seeded to native prairie plants. Woods border the long open space, and through the trees Sarah, Tim, and other volunteers cut a trail. Reese Mathews, son of former Land Institute fund raiser Randy Mathews, mulched the trail for his Eagle Scout project, and proposed the name "Path of Peace", which Sarah considers lovely. This is a setting to encourage contemplation of the cycles of life.

Heart Land can accommodate about 3,400 graves. That's about 400 graves per acre, compared with the typical cemetery's 1,000 per acre. In four years, six bodies and eight people's ashes have been buried at Heart Land. Three relatives of people whose ashes went to the cemetery have said they want their bodies buried there.

Heart Land's first burial was of Misty Miller, who in 2016 died on Interstate 70 near the exit to Niles. Her family visits the cemetery on her birthday and Mother's Day, and holds Day of the Dead picnics. Misty's children enjoy the trails and leave flowers or drawings at her gravesite.

You can't see Misty's grave – or any other grave at Heart Land – until you're almost standing on it. The marker for each is a simple metal disc about two inches across and flush with the ground. Like the head of a nail, the disc is on a short piece of rebar driven into the soil. The print on all markers is in the same plain style: names in small, all-capital letters, birth and death dates presented solely as numerals, and around the disc edge the cemetery's name. One disc reads, "Kenneth Conrow / 1 · 22 · 1933 / 3 · 18 · 2019". He was a chemist. His family got a cardboard cremation box from a mortuary, and at Sarah's suggestion decorated the lid with things he liked. They drew a chess board, a sailboat, and prime numbers.

Sarah coaches families through the steps of burial. Put the shrouded body or the box on three boards laid across the grave. Also spanning the gap lie straps or ropes. With one person at each strap end, on the count of three lift the body. This is to get a feel for things. Return the body to the boards. Now lift again, and after three other people remove the boards, the body is lowered hand over hand. "And they do it beautifully every time", Sarah said.

Buffalograss spreads around the marker for Charles Livingston / 10 · 30 · 1932 / 3 ·16 ·2018. Charlie was a surgeon who'd donated his skills in developing countries. His friends joined his family at the funeral. One friend made the oak board on which Charlie's shrouded body lay for lowering into the grave. Another, David Norlin, said there was no tent, no Astroturf. "It was more earth and earthbound", as he envisioned burials during settlement of the prairie, before mortuaries and without the metaphor of a rigid coffin to enhance eternal

Taking a shovel in your hands and moving earth into the grave to cover a body brings a feeling of connection not had when just watching. Sarah Crews photographed the burial of Kim Rea.

life. “It’s much more an acceptance of natural processes”. About a dozen of Charlie’s friends and family took turns covering him with soil. For Norlin this was the ceremony’s most significant difference. “Grabbing a shovel and shoveling the dirt in,” he said. “That is a much more visceral way of experiencing a service than sitting in a pew”. He cited psychiatrist Bessel van der Kolk on addressing trauma with one’s body, not just with talk. “You feel more involved when you intuit with your heart rather than just your head”, Norlin said. “When your hand’s on the shovel, you’re here, now”.

You can take a body to the cemetery in your station wagon or pickup or SUV. And you can take it from home – the body need never see a mortuary. Put packets of dry ice underneath to keep the body cool. Sarah gives workshops on the details of this care. Late last year she began a podcast called “A Path Home”, for the National Home Funeral Alliance. In each episode a family relates their experience with a home funeral or natural burial, or both. Sarah said that every person she’s talked with about a home funeral has found it profoundly meaningful.

Heart Land interests more than those involved in the services. Aubrey Streit Krug, The Land Institute’s director of Ecosphere Studies, uses the cemetery to teach. Kansas Wesleyan University writing students came to walk, observe, and reflect. Oklahoma State students aiming for careers in fashion were brought, with thoughts of biodegradable shrouds, to consider “closing the loop” of that extractive industry. For a conference of scholars and educators the cemetery served as an “embodied, applied place” to illustrate thinking ecospherically of limits and processes.

Aubrey never takes to Heart Land only one visitor, but instead always brings a “membership of people together”. And she thinks it a good place to explore being of a community more than human. By also showing remnant prairie surrounded by cropland at The Land Institute, she may convey grief over the extraction that built our world, and recognition that soil made our bodies. Coupling this with Heart Land and thoughts of what will come after you can be powerful, she said. “It’s a somber but beautiful reminder”.

We practice conservation, we compost, and we recycle, but when we die, Sarah said, our bodies are turned over to an industry. This can weigh on how we the survivors feel at the ceremony. Not necessarily just because of the thousands that it cost, but because we hired someone else to prepare and bury our kin. Doing it yourself is not for everyone. But participation brings meaning. You’re not just writing a check, you’re engaged.

People often don’t know they have the choice. They don’t know that it’s legal to have a funeral at home, commonly for one to three days, sometimes laying the dead in their own bed, and to bury them in a simple sheet, a handmade quilt, or a homebuilt coffin. And Sarah said that people might not realize that when someone dies, “There’s no emergency. Nothing urgent needs to happen. All we have to do is be present to the moment. Give yourself time to let your heart catch up with your head”. A visitation at home allows mourning in a familiar space.

Then, the simplest, most natural way to return a body to the earth is to have a natural burial. The cemetery is called Heart Land, as two words, because it’s not just in the heartland, the middle of America. Sarah said it’s about giving our hearts and loved ones back to the land.

Modeling the land

Before changing the world, first explore the what-ifs

JUSTIN PODUR

Consider a piece of land: perhaps it's pasture or a grain crop. To produce food on this land, you need water, whether from rain or irrigation. You need energy to power machines. You might need other inputs, like fertilizer or pesticide. You will need people working on the land, and perhaps animals too. If your crop is annual, and tilled, you will lose some soil each year to erosion. If your crop is perennial, or no-till, you may lose very little soil, perhaps none.

The land-use practices you choose have other consequences: whether your parcel sequesters carbon or emits it; whether it feeds many or a few; whether it provides habitat for wildlife or destroys it. Scale up the decisions, and the consequences become momentous, the concerns global: preserving the planet's finite land and soil, feeding its people, preventing species extinction, slowing climate change.

Even at field level, the results of your decisions are complex. And at a global scale we can't afford to test them. But we can explore the tradeoffs, and the decisions necessary to meet our goals, with modeling.

In science, a model is a representation of something difficult to observe directly. Because so much of nature is difficult to observe, modeling is indispensable. In their highly underrated book "How to Model It", Anthony Starfield and co-authors Karl Smith and Andrew Bleloch tell us that a "model is a laboratory for the imagination. You can tweak a model to see how it responds. You can argue whether the threads of logic really do knit together in a consistent fashion. You can explore its strengths and limitations. You can even guardedly make predictions and then argue how good (or poor) those predictions might be". The simplest and most elegant models can be done by an unassisted human mind. Einstein developed his theory of relativity by imagining what a person would see if they could sit on a beam of light. Not possible in the real world, but it yielded insights into the way the perception of time is relative to the observer. Galileo helped us understand motion by imagining an object moving on a frictionless surface. Such surfaces don't exist in the real world, but imagining – modeling – led Galileo to understand relationships between mass, velocity, and momentum.

In environmental science, modeling is

Erosion rates are one of many things to put in a model for predicting how well various kinds of agriculture can feed the world without wrecking it. Modeler Justin Podur is still plugging in numbers. But we know perennials in the equation will greatly reduce erosion both subtle and dramatic, like this storm last spring north of Peoria, Illinois. The photographer, James Alwill, placed blocks for erosion control, but silt filled them and buried his own plantings.

of importance: we can, and do, run small-scale experiments and make observations in the field, but we can't change global policy just to see what happens. Instead, we build models and explore what-ifs. These what-if scenarios are the consequences of a set of assumptions. The better we know and make explicit our assumptions, the more our models help us refine our thinking. Models are especially powerful when the disagreement of observation with model predictions forces our hidden assumptions into the open. Thomas Kuhn's "Structure of Scientific Revolutions" describes how a growing body of counterevidence can make scientists' invisible assumptions increasingly difficult to ignore, leading to an overturning of old theories and their replacement with new ones. In astronomy, Ptolemaic circles were replaced with Newton's laws, which were in turn replaced by Einstein's theory of relativity. These were great theoretical innovations, which demanded changes to our models.

Modeling is not just about astronomical representations of the cosmos. Industrial engineers are consummate modelers, applying an ever-expanding toolkit to a growing class of problems in the fields sometimes called operations research (OR) or management science. Operations researchers use mathematical models to solve business problems. Among the most basic and powerful tools in OR is the optimization model, implemented through linear programming (LP), which is a method that can solve many problems so long as they have some specific mathematical properties.

The first LP models were developed independently in the Soviet Union and in the United States – in both cases with a view to the efficient allocation of finite resources such as metals, energy, and factory time for the allied effort in World War 2. After the war, the Soviet Union and other countries following the Soviet model used optimization models to plan their economies, while multinational corporations used optimization and simulation to model their operations.

The economic ideas adopted by the US, Canadian, and other governments since the 1980s, sometimes called "neoliberalism", assumed that markets were inherently optimal – that with them, optimization would take care of itself. More and more effort went into financial market analysis, and government economic planning and optimization were sidelined. Turning away from problems of allocating resources according to a plan, modelers focused their efforts on trying to predict market price fluctuations. But it turned out that trying to predict what others will do in a market is more difficult than deciding on an optimal allocation of resources. Decades later, forecasting the market remains the stuff of science fiction. Corporations kept on planning, however, and with proposals like the Green New Deal on the table, economic planning could be making a comeback.

The return of planning would give us more tools to address the climate and other environmental crises. The Intergovernmental Panel on Climate Change 2019 report on land use notes that "Market-based policies such as carbon taxes, fuel taxes, cap-and-trade systems, or green payments have been promoted (mostly in industrial economies) to encourage markets and businesses to contribute to climate mitigation, but their effectiveness to date has not always matched expectations". The IPCC is being euphemistic. In fact, market policies to address climate change have been a spectacular failure. In Land Institute researcher Stan Cox's book "The Green

New Deal and Beyond", he reports several such failures. Among them: Researchers for the Institute of Applied Ecology found that 85 percent of projects funded by the Kyoto Protocol would lower greenhouse gas emissions no more than what would have happened anyway. Better not to trust the market's magic. Models are better used to plan the allocation of resources in a rational, hopefully optimal, way.

To use a model for optimization, you decide on your *objective*. Often in business, the objective is to maximize profit. Sometimes it might be to maximize revenue, or to minimize cost. In agriculture, it might be to maximize yield.

Next, you identify *constraints*. Maximizing profit in one year might be a fine goal, but not if you must close your business in the following year because you ran the machines into disrepair or sold off all your seed corn. So, you might add a constraint that states that you must conserve a certain number of seeds for next year, or that you can only run your machines for a certain number of hours in a day.

You also must identify your *decision variables*. In business, this might be how much of each of your products you produce, how much of your time you use in each activity – in short, how you allocate your resources.

Speaking mathematically for a moment, optimization models are formulated like this: maximize some objective function, subject to some constraints, by manipulating a set of decision variables.

We can use this setup to model global land use. We enter decision variables like these: should the land be natural prairie or forest, should it grow corn or wheat, should it be planted with perennials or annuals, should it be pasture or a biofuel plantation?

In our global land use model, we have several options for an objective function: we can try to maximize the amount of carbon sequestered in terrestrial ecosystems; we can try to minimize the amount of soil erosion; we can maximize the amount of calories produced for consumption; we can

Instruments tell how much carbon a field of intermediate wheatgrass is moving from the atmosphere to the soil, and their data can be plugged into models for how such perennial grain crops could help lessen climate change.

meet a certain level of consumption (using a constraint) while minimizing food waste.

Our constraints are severe: we don't want our land use to drive species to extinction. We need to feed a global population that will continue to grow for a few decades. And we need to do so in a way that doesn't erode our soil.

Perhaps the most important modeling in the world today is organized by the IPCC, which has considered scenarios from business as usual to conservation-oriented, and concluded that we can help check climate change even as we feed the world's people, if how we use land moves carbon from the air to the soil.

Here is the IPCC's breakdown of how Earth's 130.4 million square kilometres of land are currently used: infrastructure (1.4 million), cropland (15.9 million), grazing land (48 million), forests (28 million), and natural land (37 million). Future land use scenarios plan to change the amount of land in each of these uses to optimize benefits and minimize harms to society and environment.

With its focus on greenhouse emissions from agriculture, the IPCC proposes increasing forests and energy crops, which rely on carbon-fixing, erosion-checking perennials, and reducing cropland, pasture, and natural lands. In one section of the report, Land Institute Research Director Tim Crews explains how perennials sequester carbon and build soil rather than lose it.

In Nature magazine, University of British Columbia researchers Zia Mehrabi and N. Ramankutty make a different projection, taking up the challenge of wildlife conservationists who call for leaving half of Earth's land unused – for leaving it to nature. They found that we could still feed the world, but only by agricultural intensification – increasing the amount of food produced per unit of land – and eating less meat. Pastureland would be decreased.

The IPCC's climate-agriculture models and Mehrabi and Ramankutty's "half-earth" agriculture model are just two examples in a growing field of modeling different aspects of global land use. What I wanted to do while on sabbatical last summer at the Land Institute was ask: how far toward sustainability goals can we advance by scaling up the perennial polyculture agriculture that is being developed here?

As many modelers do, I started with a coarse-scale spreadsheet using data from a few sources: the IPCC's land use estimates; population projections from the United Nations; geologist David Montgomery's estimates of erosion under till and no-till agriculture; researcher Emily Cassidy's estimates of how many people could be fed with different mixes of crops; and the aforementioned "half-earth" study.

I also considered that carbon can be sequestered even without converting cropland to forest: by basing our diet more on plants, by reducing food waste, by growing perennial grains, and by giving cropland, grazing land, and forests better management – how you take care of what's aboveground can greatly affect what happens below. This all could free land up for natural areas, which are the sequestration champs – though the room we have for that depends on population growth.

In one of my optimal scenarios, I attempted to preserve all existing natural areas, to feed 9 billion people, and to maximize the amount of land under perennial grain crops, including conversion of several million square kilometers of pasture. All the land under biofuel and feed grains, as well as half the lands under annuals, are also converted to perennial grains.

An important aspect of modeling, especially after the model is built and running, is called sensitivity analysis. In this phase of work, the modeler determines the sensitivity of the model's results to changes in the model variables. My model was sensitive to the yield of perennials compared to annuals: the higher the yields of the perennial grains, the easier to meet all the other objectives – biodiversity, people fed, carbon storage. There are optimal solutions with higher numbers of people fed, but this will reduce lands for biodiversity conservation. Likewise, more stringent biodiversity constraints require either higher yields or a greater adoption of plant-based foods, or both. In a sense, the whole modeling exercise provides a structured way of thinking about these trade-offs in a quantitative way.

As the work-in-progress continues, I will add layers of complexity to the model: more detailed spatial data on land uses, soil erosion rates in different land uses, yields of different crops, conservation importance of particular parcels – which, for a global model, can be thousands of square kilometres in size.

Based on the modeling so far, we can say that if the yields of perennials can get close to those of annuals, and if some extra land can be freed up, by dietary shifts to less meat and the reduction of food waste, then a steady-state agriculture could be achieved at the global scale that feeds the world, conserves wild spaces, and does not strip the soil or exacerbate climate change. Perennials will have an important place in that agricultural future.

Justin Podur teaches and researches landscape ecology at York University in Toronto, Ontario. He wrote "Siegebreakers", a novel of modern Palestine.

The five-day farm bill

KACEY STEWART

On the first day,
we gather, we grieve, we intend
to listen, to learn
together.

On the second day,
we ask questions
knowing we will not answer them
– not this week anyway.

On the third day,
we open eyes,
and see the invisible;
not the contents, but the connection.

On the fourth day,
we kneel down in the dirt,
no, the soil.
What else could make us clean?

On the fifth day,
we ever so carefully, cautiously
get right to work,
offering it as inheritance.

The writer is PhD student in English at the University of Delaware and was an extern in The Land Institute's Ecosphere Studies. His field is how data presentation affected early Americans' perception of the environment.

Research Director Tim Crews explains how perennial roots can lift water through the soil they helped make, at The Land Institute's Prairie Festival last September. For a congressional climate change committee, Crews and institute President Fred Iutzi wrote about how these roots can sink carbon to help check climate change. Scott Bontz photo.

Land Report shorts

Report for House committee

At request of the US House Select Committee on the Climate Crisis, The Land Institute wrote a report on the importance of perennial grains in curbing climate change, by moving carbon back from the atmosphere to the soil, and in making agriculture more resilient to growing conditions that are already bound to shift. The report says there's now proof of concept for perennial grain crops, because of work by us and our collaborators around the world. But funding is miniscule, and time of the essence. The report recommends increasing public and private research funds in the US to $100 million in five years. This is more than 12 times what The Land Institute now can apply to the work, directly in Kansas and with colleagues, but it is far less than the billions already devoted to research for annual grains. "At current funding levels, full development and deployment of perennial grain crops is still decades away", say the report's writers, Land Institute President Fred Iutzi and Research Director Tim Crews. "While no level of funding can bring transformational change to a biological system overnight, a major investment in perennial grain crop research could potentially cut decades from the timeline".

The report summary opens by noting that the most beneficial way to get carbon out of the atmosphere is by moving it back to the soil, and that the most potent route for this sequestration is the millions of square miles now in production of annual grains, a massive carbon loser. "While discussions of soil carbon sequestration often emphasize uncertainty, it is unambiguous in the scientific literature that the highest levels of carbon sequestration achievable occur when lands previously planted to annual crops are converted to continuous perennial vegetation". With their reduction of machinery use and possibly fertilizer and pesticide, perennial grain crops could also greatly reduce greenhouse gas emissions.

The climate committee is to submit policy recommendations to Congress by March 31. Florida Democrat Kathy Castor chairs the bipartisan, 15-member committee. The Land Institute will provide a version of its report to philanthropies.

Carbon numbers

Research estimates, in gigatons. A gigaton is 1 billion metric tons.

Carbon in atmospheric carbon dioxide:	800
Organic carbon in the top 3 meters of soil:	2,770
Soil carbon that has been lost because of farming:	50
Maximum carbon returned to soil with better cropping and grazing:	1.35 per year
With a combination of new approaches including perennial grains:	2.16 per year

First wheatgrass variety

A commercial variety of a perennial grain pioneered by The Land Institute, then refined by the University of Minnesota, has been released, a first in our work to revolutionize agriculture. The crop is intermediate wheatgrass, and the variety is called MN-Clearwater, a nod to the cleansing effect of wheatgrass roots and to the headwaters county of the Mississippi River.

In 2011, Land Institute wheatgrass researcher Lee DeHaan established seedlings in Minnesota, and Prabin Bajgain, then a graduate student, helped transplant them. More than 2,500 plants were evaluated for two years in St. Paul. MN-Clearwater was derived from seven elite parents. The university evaluated the variety over three years at several places across the state. Bajgain said it is among the shortest stature wheatgrass populations in Minnesota and the second best in seed yield. It's adapted to the region, which is cooler and wetter than Kansas. It matures uniformly and resists toppling, both important for harvest, and it threshes decently. Several improved candidate varieties are in trials. But Kernza®, our registered trademark for grain and food made from intermediate wheatgrass, has already been used by brewers and bakers, has made a name for itself, and is in demand, Bajgain

The Land Institute's most advanced perennial grain crop has found commercial release through a variety developed by our collaborators at the University of Minnesota. It's also drawn the attention of mainstream media, including freelance editorial cartoonist Greg Kearney.

said. “We thought that the time was right”. The amount of seed available is small, and it can go only to licensed growers.

Like rye, intermediate wheatgrass is outcrossing, meaning one plant does not pollinate itself well, as can wheat. So, although MN-Clearwater may look different from other wheatgrass types in color and form, its genetics remain diverse. It’s called a synthetic variety, with each batch of seed coming from the same set of ancestors. These can live indefinitely. Since they outcross, results might vary a little from year to year. But overall, the variety’s traits should remain consistent.

After earning his PhD, Bajgain worked elsewhere for three years to improve wheat, rye, barley, and oats. He returned in 2017 to pick up the work of Minnesota’s previous wheatgrass breeder, whom he had helped as a grad student. “It’s been quite a journey”, he said. And for a tree lover, one who keeps tropical species in his home, to see perenniality coming to grain crops is especially exciting.

The Land Institute has said that development of entirely new crop species could take decades. But deciphering plant genomes and statistical tools have sped progress. The acreage planted to intermediate wheatgrass as a grain crop has reached more than 2,000, involving farmers from New York to California. Fields are most numerous in southern Minnesota and central Kansas. Certified organic acreage is 850, conventionally farmed acreage 734, and 424 acres are in transition to organic. In Europe are another 400 acres.

Wheatgrass processing plant

Another commercial first for our perennial crops: a grain processing company has assembled a production line specifically for food-grade cleaning and de-hulling of Kernza®, our registered trademark for grain from intermediate wheatgrass. Healthy Food Ingredients opened the line early last year at its plant in Valley City, North Dakota, and has handled something under 50,000 pounds of wheatgrass from farms in the upper Midwest. As acreage planted to wheatgrass grows, the poundage could rise to millions, said Chris Wiegert, HFI’s chief soil health and sustainability officer. The company does not yet mention wheatgrass on its website, to avoid calls for a product still in relatively short supply. Wheatgrass is very different from other grains that the company handles, Wiegert said, and required special equipment and its own processing line.

With the registered trademark “Cultivating goodness”, HFI sells for its health benefits a purple maize called Suntava, plus flax, amaranth, buckwheat, chia, emmer, spelt, millet, quinoa, and teff, along with the more conventional grains, a handful of vegetable oils, and more than a dozen kinds of beans. In addition to the facility at Valley City, which is west of company headquarters in Fargo, it has three more plants: across the river from Fargo in Moorhead, Minnesota; in Hastings, Nebraska; and in Watertown, South Dakota.

Yields well over doubled

Five cycles of selecting and breeding the best intermediate wheatgrass plants at The Land Institute increased yield – the weight of seed per area of land – 145 percent. Researcher Lee DeHaan’s charted figures show a steady rise over the generations. He hopes to see yield rise another 100 percent over the next 10 years. The average weight per seed has risen by half. Yield combines

that with an increasing number of seeds. The amount of free threshing seed – those that don't demand special dehulling machinery after harvest – rose from under a fourth to more than a half over the five breeding cycles. The cycles entailed growing and selecting large numbers of the best candidates from up to 20,000 mature plants in the field. DeHaan now uses genomic selection, analyzing the DNA of seedlings and selecting the best 100. He also no longer evaluates improvement generation by generation, but grows different generations side by side, and will test candidates to produce crop varieties.

Civic scientists

In the fall Land Report, Aubrey Streit Krug, director of our Ecosphere Studies program, wrote about enlisting more than 40 people around the nation to grow silphium and study this perennial crop-in-the-making. From this we're learning how to organize a community to gather information. The project is called civic science. After the first growing year of observation, participants were surveyed. Here are excerpts.

"I remember feeling pure joy when I watched plants thrive, feeling that their roots were connecting Virginia to Kansas,

Konilo Zio with intermediate wheatgrass, seed yield for which is up 145 percent in five breeding cycles. Zio studies at the Higher School of Agriculture in France and interned at The Land Institute last summer. Scott Seirer photo.

and helping improve the way we eat food, but if I had to pick one moment, it would be one of the many times I explained the project to a friend, neighbor, or person hired to do work in the yard or house". – Anne Stratton, mother of Land Institute researcher Chase Stratton.

"What surprises me is recognizing the value of relationships in the world of science. I am most ashamedly like others who believed scientists and other brains will figure out solutions to complex problems in how we farm and what we eat. This project affirms the belief of very learned people doing research, but taught me the importance of those people creating relationships with others like me". – Janelle Streit, mother of Aubrey Streit Krug.

To know your enemy

Crop protection geneticist Kathryn Turner has been trying to find what's causing strangely clear veins and constricted and twisted leaves in our crop plant silphium. In some fields, especially if water-logged, symptoms can be extreme, and plants won't even flower. Lead silphium researcher David Van Tassel found images of lettuce with similar symptoms caused by a virus. After tests for 19 viruses all came up negative, infected tissue was sent to a company in the Netherlands for RNA sequencing. They found the most likely candidate to be Dahlia mosaic virus. But the symptoms of DMV – and for other viruses – can greatly vary, and often plants showing no symptoms are infected.

This virus has three strains. The most common, DMV-D10, can reach all of the plant's tissue, including the seed. Avoidance or resistance to this kind of infection would be unlikely, so instead we'd try to find tolerance – despite infection the plant still yields well. The DMV-D10 strain is endogenous, meaning the host's genome has integrated viral DNA. It can be latent until a stress such as wounding or perhaps flooding activates it to become infectious. Turner is trying to nail down the strain we have and is collaborating with an interested specialist at Washington State University.

Moldova relations

In December, Research Director Tim Crews made our first visit to the eastern European nation of Moldova. "Farming Forever" was the name of the conference at Alecu Russo State University of Balti. Researchers mostly from Europe and Russia talked about no-till and organic farming to replace conventional practices in a nation with a relatively poor economy but with rich soils that originated under grasslands, much like the soils of Kansas. Crews wants the transformation to include perennial grains, and he plans to send seed for testing. Alecu Russo faculty member Boris Boincean, born in Ukraine and educated in Moscow, has visited The Land Institute three times. He and British researcher David Dent have a new book about managing those rich soils, "Farming the Black Earth". Crews wrote the forward.

Self-love in the silphium

Some plants can pollinate themselves, but in other species they depend on pollen from neighbors. For a self-pollinating crop like wheat, breeders can make a variety quite homogeneous – with consistent desired traits, and the undesirable traits culled. A wild out-crossing species is quite heterogeneous, with traits good and bad hidden as recessive alleles. Silphium, The Land Institute's

oilseed crop, is an out-crosser. But Stephan Reinert, a University of Colorado researcher then working in Fargo, North Dakota, with the USDA's Brent Hulke, a former institute graduate fellow, found that some improved plants from The Land Institute could self-pollinate some of their florets, the small flowers that make the head of a composite such as sunflower. This was in our chosen silphium crop species, *S. integrifolium*. Reinert found even higher selfing in a related species, *S. perfoliatum*, and in crosses of the two.

Last year he and our silphium technician, Sydney Schiffner, went fishing in our field of offspring from wild plants that had been collected across silphium's range from Kansas to Indiana and Wisconsin to Mississippi. Eighty percent of the plants with heads bagged to prevent cross-pollination made zero seed. But the rest set at least two or three seeds, lead silphium researcher David Van Tassel reported, and some set 10 to 30. If silphium breeders can capitalize on this to make silphium self-pollinating, they can achieve homogeneous, inbred lines. This will simplify and speed deciphering the genetics of the new crop plant. It also might enable treating silphium like modern corn, with which inbred lines are crossed to make a hybrid more vigorous than its parents. Unlike with corn, farmers would not have to buy and plant new seed every year.

Sydney Schiffner divides root balls to propagate silphium and find the plants that are both self-pollinating, which will help in breeding, and vigorous.

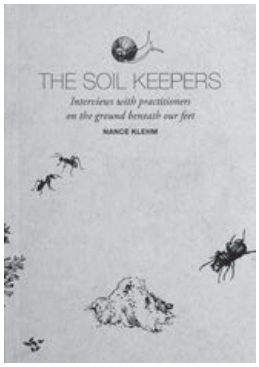
Reinert earned his PhD in plant breeding from the University of Bonn. He sought post-doctoral work in the United States to improve his English, and was hired by the University of Colorado, with funding from the Perennial Agriculture Project, which we administer for the Malone Family Land Preservation Foundation. He spent two years in Fargo to hone his plant breeding skills, focused mostly on the selfing problem and on crossing silphium species. He also studied how to knock silphium seed out of its strong dormancy, with cold and chemistry. Reinert moved to Boulder last May, and has concentrated on bioinformatics, studying silphium genetics with computers and statistics.

"Perennial grains are the future of sustainable agriculture, and Germany needs that as well", Reinert said. He would like to start his own silphium program and pursue at least three tracks. One is to synchronize

flowering time, which in the wild runs all over the map. Seed should grow and mature together for harvest – though the timing might be varied among crop varieties according to place. Reinert also wants to make sure that selection and breeding for a trait such as higher oilseed production doesn't cut into energy going to traits such as disease resistance and perenniality. And some contributions to making a grain crop might take a long time to find, buried in silphium's great genetic diversity. Reinert wants to induce the mutations with radiation. He made first steps with cancer treatment machinery at a Fargo hospital.

"The Soil Keepers"

Nance Klehm restores soils and runs Chicago-based Social Ecologies, which helps city dwellers build healthy, ecological systems for soil, water, and community. She's also made a book of interviews with more than 40 people around the world whose work involves soil. Sometimes the connection is loose, but Klehm is raising consciousness of how much we're all part of soil's life and vice versa. Subjects of "The Soil Keepers" include a painter, pigment forager, ceramicist, miner, soil chemist, manure composter, architect, geologist, botanist, filmmaker, civil engineer, hydrologist, disaster anthropologist, landfill engineer, wastewater writer, and rainwater harvester, plus activists, farmers, and one misanthropic "social fugitive" in the Utah desert. You get lots of angles. Aside from Klehm's own introductory essays, you also get raw Q&A style, with sentences apparently left as they were spoken, complete with run-ons. And there are many typos.



Co-evolution of plant and plot

Plato's dialogues proposed that in a spiritual realm are creation's ideal forms, timeless and unchangeable blueprints for our physical world's imperfect imitation. Somewhat like this, a plant breeder can have a crop ideotype, vision of a plant made perfect. But the ideotype is a goal that's adjustable, according to what the breeder learns is possible. This includes traits such as maximizing yield, not dropping seed before harvest, and resisting diseases. Many of these traits depend on many genes, and improvements can seem to entail tradeoffs. But through generations of breeding, the links can be disentangled. Here, an old crop like maize is well along. With wild perennial species, Land Institute breeders have started from scratch. It is over years of watching plants perform, and by sorting gene effects from field effects, that they refine their best guess of how a new crop could look and work, and how to get there.

The individual plant at harvesttime, especially the perennial, with its deep roots, is only the tip of what to know. Even before getting to effects of different soils and climates, there is how plants work among their neighbors. Do they grow and produce best when grown a foot apart, or when three feet apart? What nurture – weeding, fertilizing, etc. – best fits a species so recently come in from the wild? How should that change as the plant is tamed? We need not just a crop ideotype, but also a *cropping system* ideotype.

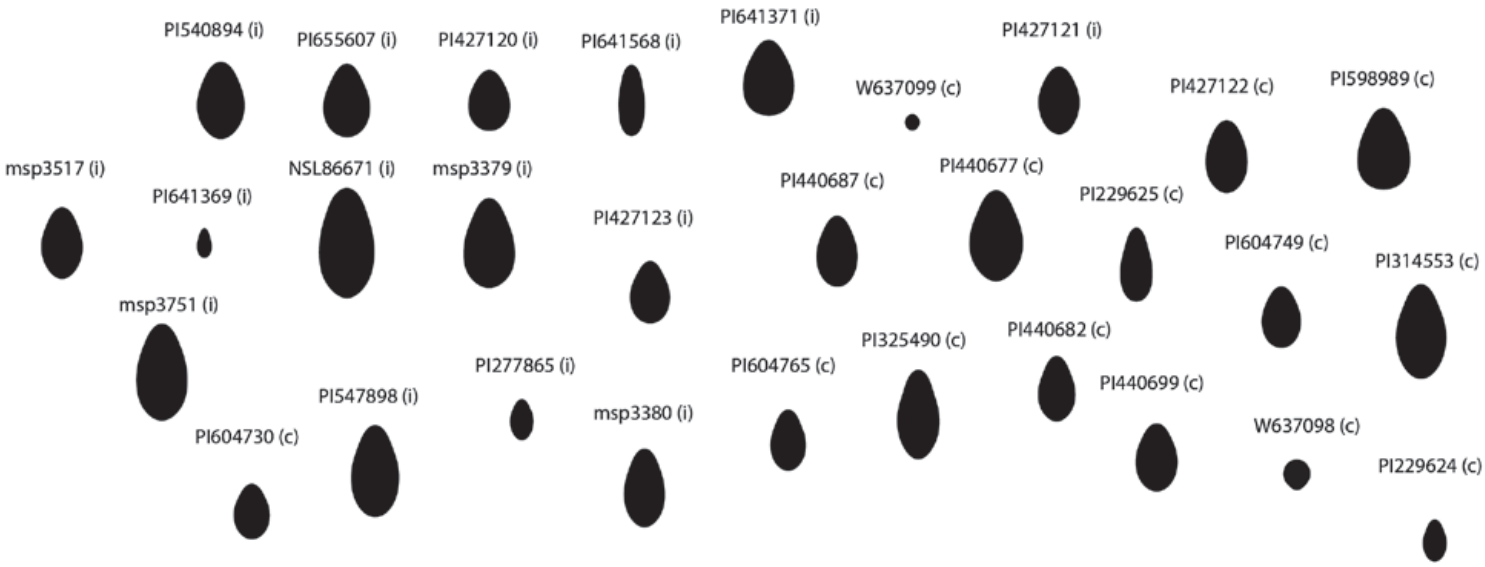
And the two should not evolve independently. Something as subtle as the

angle of a grass leaf's growth from the stem combines with the plant's nearness to neighbor for how the leaf captures sunlight to make seed and for how it shadows a weed. Belowground, perennials' lasting roots can choke one another and cut yield. Breeding might help: maize plants have been selected to not fight their neighbors. But by any route, plant spacing is key.

For a new agriculture, add to this the complexity of alternating species from row to row, with different shapes above and belowground. This way a legume and its symbiotic root bacteria moving nitrogen from atmosphere to soil might save the neighboring grain crop from need for so much synthetic nitrogen, and its huge fossil carbon cost. But a mature grain crop towers over the typical forage legume. How near can the two stand without the one shading the other? Instead of alternating every row, should there be a pair of legume rows between each grain row?

Legume breeder Brandon Schlautman is fashioning a cropping system ideotype – "simultaneous adaptation of a crop to a cropping system and of the cropping system to the crop". From the National Plant Germplasm System, a public and private collaboration to preserve plant diversity, he obtained seed from 150 populations of a promising legume called kura clover. He and his technician, Spencer Barriball, seeded plots with the smidgen of seed available for each population. After harvest they took about 900 cut plants to the lab. From each plant Barriball removed three leaves of three leaflets each, and photographed them, a job that took about 60 hours. Schlautman wrote code to customize algorithms for a computer program that measured in the photographs the leaves' color, length, width, and shape.

Results were compared, and the 150 original accessions were narrowed to a core of 30 that express 90 percent of the leaf variation. Another 30 represent root growth



Searching for the ideal crop, here the legume kura clover, includes comparing leaf sizes, shapes, and their effects.

variation, and other groups were selected for yield and for vigor. The cores are of 30 because there's only so much time and space for plots devoted to each trait. And because Schlautman and Barriball's starting collection from the NPGS was small, they will continue to accumulate seed from these populations before sowing replicated plots to judge how the various traits and farming arrangements add up. Kura clover will grow with intermediate wheatgrass, our most advanced perennial grain crop, to test, among other things, whether the legume's leaf variations affect compatibility and competition. If Schlautman and Barriball find that a leaf type matters, they can select for it with confidence. Whether it does or it doesn't, they'll be able to refine their crop and cropping system ideotypes.

Cox moves to ecosphere work

After four decades of plant breeding, the last half at The Land Institute, Stan Cox has joined our Ecosphere Studies department to work in food systems, energy, and economics – any aspect of the world's ecological troubles. Foremost in his mind is climate change. From 2016 he has increasingly written and collaborated on how to "flush fossil fuels out of the economy" with a statutory declining cap on their extraction, along with production planning and rationing. In the past two years he took as a clear message from climate experts that humanity has less time to avert catastrophe than had been thought. "We've got to turn this tanker ship around in the next ten years", he said. Now in his mid-sixties, he decided, "Let me do what I can in this ten-year period".

Even while breeding plants, Cox took to new fields and explained them to general audiences. His deal to join The Land Institute in 2000 was for three months off each winter, so he was able to write books about health care, air conditioning, rationing, and human coping with natural catastrophes. His latest, to be released in May, is "The Green New Deal and Beyond". He also wrote for our early 2000s op-ed service, the Prairie Writers Circle, appearing in newspapers that included the Los Angeles Times and The Washington Post.

Cox

For his master's degree Cox worked with oat, and he conducted his dissertation field research with sorghum in India. For 13 years he worked for the USDA in Manhattan, Kansas, improving disease-resistance of wheat by crosses with wild ancestral species. Before joining us, he returned to India, helping a nonprofit public health service and teaching high school. He led our work to bring sorghum crosses with the rangy perennial johnsongrass to grow more and more like a grain crop, with compact seed heads and larger seed, while remaining perennial. He will continue to lead sorghum research until we hire his replacement, for whom he will serve as mentor.

Cox said he'll miss being in the field with plants, harvesting seed and taking notes. He won't miss weeding.

From one sorghum seed

A couple dozen unusual sorghum plants growing in The Land Institute's greenhouse this spring might be crucial in accelerating development of perennial sorghum. Most

first-generation hybrids from crossing annual crop sorghum with perennial *Sorghum halepense* are tetraploid – they have four chromosome sets. This complicates breeding back for crop traits from annual sorghum, which has only two sets. Some of our recent hybrids are also diploid. They produce more and larger seed than do tetraploids, and the traits of their offspring are more stable. But they and their descendants have yet to make rhizomes, the underground stems that go with perenniality.

A plant called S3011-A1, grown in Salina in 2018, had three sets of chromosomes. Triploids are rare and usually sterile. But this one made three seeds, and one of them germinated. In its formation, a chromosome set was sloughed, so the offspring was diploid. And it turned out to be the first diploid plant derived from *S. halepense* that's capable of producing rhizomes. Cox kept S3011-A1 alive in the greenhouse and returned it to the field last summer. This time the plant set almost 200 seeds, and another triploid made a few dozen. About one-third of this collection germinated, and about 30 of the resulting plants produced rhizomes in the greenhouse over the winter. Chromosome counting is not quite completed, but Cox has at least 15 and potentially as many as 25 rhizomatous, diploid plants. Seed from those plants will be sown in the field this spring. Having one rhizomatous diploid plant a year ago was important, but a single plant can be a genetic bottleneck. Now, the existence of many such plants increases the diversity of this unique gene pool. And diversity is essential to progress in plant breeding.

An emerging seed head of hybrid sorghum, a perennial crop whose breeding might be sped by plants recently found with simpler genomes.

Steering pests, by odor

A Kansas State University student found a sex pheromone that attracts a moth that has devastated Land Institute silphium plants, and other pheromones that repel it. Our crop protection ecologist, Ebony Murrell, called the results exciting, and plans pest management tests this year. The pheromones could be used to keep eucosma from laying eggs in silphium fields, or to attract them to traps. Silphium, a perennial in the sunflower family, is our oilseed crop. Kaitlyn Ruiz is a K-State undergraduate working with Rob Morrison, a USDA Agricultural Research Service entomologist

Kaitlyn Ruiz found pheromones that attract eucosma moths, and other pheromones that repel them, which may help us manage the sometimes devastating pest. Ruiz photo by Rob Morrison, moth photo by Edy Chérémond.

exploring pest management with fewer insecticides. Ruiz set sticky traps amid our silphium plots. The traps had either an odorless control or one of eight pheromones manufactured for other, closely related moth pests. Eucosma has not been well studied, because silphium is a new crop and the only thing that eucosma eats. Ruiz found that one pheromone was 2.5 times more attractive to eucosma than was the control. It was 1.5 times more attractive to other moths. On the flip side, three pheromones repelled eucosma, one of them completely, and none significantly repelled other species.

The garden is planted in wildflowers

THOMAS FOX AVERILL

I planted a wildflower. No, not wild like Star of Bethlehem, brought back from the Crusades to France, Spain, England. First planted as simple border, it proved itself a creeper, a crawler, a spreader, an interloper, a pest and then a weed, the black sheep of the lily family.

And no, not wild like clematis, vining everywhere once planted, the tiny profusion of flowers that attract hummingbird and bumblebees turning to tiny seeds that fling themselves everywhere until the neighbor grumbles as she pulls the tendril after tendril from her fence.

And no, not wild like ditch lilies, steady in adding bulb to bulb, crowding out grass, blooming, then withering, stalks stabbing the air, leaves falling and curling on the ground, matting the earth so the plant can dominate through the next year, and the next.

And no, not wild like tansy, planted for medicinal purposes but each root spreading so fiercely that digging it out only gives it new plans to sprout from the fragments, no piece too small, no tiny seed too discouraged to germinate no matter the soil – the more disturbed the better – until the only way to tame tansy is to turn loose sheep who will make it disappear until another season pulls it from the earth.

Yes, I planted a wildflower, one that belonged where it was planted, one that the years had accustomed to sun, wind, rainfall, season. It was not wild at all. In fact, it was settled, belonging where it was just as it had for centuries. And when it bloomed, sprays of flowers waving its arrival, color so intense against the palette of prairie, all the earth seemed content with its common sense, with its indigenuity.

Averill is professor emeritus of English at Washburn University in Topeka, Kansas. He writes about human relations with plants and nature, including on a web page called Garden Plots.

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Megan Gladbach dumps seed of a sorghum hybrid into a tray for weighing. The hand on the computer screen is that of Jarrod Fyie, who sits out of view to the right, working in a photo booth. His camera points down on brightly lighted seed. After separating the grains from one another, he'll photograph them for a computer to turn the image into numbers about seed size and shape. The hope is to correlate seed measurements with genome types, so researchers can find genomic markers for plants with larger, higher-quality seed, which will simplify and speed breeding of the new perennial crop. For more, see page 25. Scott Bontz photo.